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ITALIAN PETROLOGICAL SKETCHES.

II. THE VITERBO REGION.

Bibliography.—The writings of the early Italian geologists, such as Brocchi, Pareto, and Ponzi, are of such small petrological value at the present time that nothing need be said of them here.

The first to describe the region according to more modern methods was vom Rath,[1] who devoted parts of two of his Italian *Fragments* to its description. This is largely topographical, but contains many petrographical details and some analyses, which will be referred to later. Stoppani[2] also, in 1873, gives a brief account of the region.

Through the kindness of Sig. Caposavi I was enabled to obtain a copy of Dr. Barbieri's pamphlet, entitled *I Vulcani Cimini e Vulsinii* (Viterbo, 1877), which is out of print and very rare. It proves to be a popular but graphic sketch of the geological history of this and the Bolsena regions.[3]

In 1880 A. Verri[4] published a somewhat extended description based on personal observations. Accompanying it is a geological map, which is on a small scale, and a much idealized section. His petrographical determinations are not based on microscopical examination of thin sections, and hence leave much to be desired. After the descriptions of the various rocks and remarks on their distribution, he gives a sketch of the Tertiary and post-Tertiary history of the volcano, as he deduces it from his observations.

[1] VOM RATH, Zeit. d. d. Gesell., XVIII, 577–585, 1866; XX, 294–307, 1868.

[2] Corso di Geologia, Milan, 1873, III, 387.

[3] This is mentioned since the work is scarcely known, and the bibliography published in the Boll. Com. Geol. Ital. for 1886 mentions it only by title.

[4] VERRI, Atti Acc. dei Lincei., VIII, 3–34, 1880.

A few analyses of eruptive rocks from this center were published in 1884 by Ricciardi,[1] but, as he expressly states that they are of groundmass carefully freed from phenocrysts, they are unfortunately of comparatively little use to us.

A few years later Bucca[2] published some short petrographical descriptions of various rocks from this locality. He concludes that two distinct types are found in the region, "one essentially trachytic, the other leucitic. These two types often appear isolated and clearly distinct; at other times there has been a mixture of one with the other." He further thinks that the trachyte is younger than the leucitic rocks and argues from this an increase in acidity during successive eruptions.

In 1889 appeared the latest works on this region so far as my knowledge extends. The paper by G. Mercalli[3] is a purely petrographical account of the principal rocks with short but useful descriptions. He distinguishes the two types of trachytic and leucitic rocks, and shows that the latter are later than the former. He also gives numerous mineralogical details of a series of ejected blocks, which are also described elsewhere by E. Artini.[4]

The other paper of this year is that of Deecke,[5] which constitutes one of his series of excellent articles on Italian geology. The first part of the article is devoted to a discussion of some of Verri's views and an exposition of his own regarding certain features of the volcano. The second part describes at length the ejected blocks found in the tuffs of Monte Vico, and the third describes various eruptive rocks collected by himself. An almost complete bibliography precedes the paper. Lacroix[6] also describes many of the ejected blocks and segregations from this region.

The best maps are those issued by the Italian government.

[1] RICCIARDI, Atti Acc. Gioen. Catania, XIX, 1884.
[2] BUCCA, Boll. Com. Geol. Ital., 1888, 57–63.
[3] MERCALLI, Rendic. Institut. Lomb., XXII, 1889.
[4] ARTINI, Atti Acc. dei Lincei, VI, 1889.
[5] DEECKE, Neu. Jahrb., B. Bd. VI, 205–240, 1889.
[6] LACROIX, Les Enclaves des Roches, Macon, 1893.

The southern part of the region is included in the completed Bracciano Sheet (Foglio 143, scale 1:100000) of the Geological Map of Italy.

Topography.—The Viterbo region lies a few kilometers southeast of Lake Bolsena, Viterbo being the chief town and best headquarters. It resembles in many respects the Bolsena region. East of Viterbo and in the northern part of the region lies the group of high hills known as the Monti Cimini, the early bulwark of the Etruscans against the Romans. The largest of these is Monte Cimino, a curving ridge running north and south, convex toward the east, its highest point 1053 meters above the sea and about 800 above the plateau of Viterbo. Connected with this and forming part of the same orographic mass are the lower Monti di Vitorchiano, Soriano, and La Pallanzana.

These, it may be said here, were formed by the older eruptions of the region. They are wholly built up of volcanic materials—lava streams and beds of tuff and a tuff-like rock. Stretching out around Monte Cimino to north, east, and west are lava streams and beds of trachytic tuff.

Immediately to the south of Monte Cimino, and southeast of Viterbo, is the most striking feature of the region—the great crater-ring of Monte Vico. This is almost circular in shape, its symmetry being broken by the projection of Monte Fogliano in the middle of its western side. Its greatest diameter—from north to south—is about five kilometers, and its widest part east and west is nearly as great.

The highest point of its rim is the summit of Monte Fogliano, 963 meters above sea level, the highest point on its northern edge being 896 meters, on the east 696, and on the south 607. It thus resembles the Bolsena, Latera, and other craters of Italy in having its southern rim the lowest. The inner slope is quite steep. Vom Rath estimates the average at 20°, which, judging from my own observations, seems much too low. In places, as on the east, and, according to vom Rath, on the south, it is quite precipitous. When not hidden by forests of oak trees it is seen that the walls are made up of beds of tuff with lava streams

and masses of lava blocks, tuff generally constituting the highest part of the ridge. The lavas of Monte Vico are predominantly leucitic, a few phonolites also having been observed.

The southern part of the interior of the crater is occupied by a lake whose surface is 507 meters above sea level. Its depth does not seem to have been ascertained, but it is apparently shallow. At the southeast corner an emissary has been cut for drainage purposes. Eventually the lake will probably give place to a plain, through drainage of its waters and filling up by denudation of the surrounding easily eroded tuff walls, as is the case at Agnano and elsewhere in Italy.

In the northern part of the crater there rises from the alluvial plain left by contraction of the lake from its original limits the so-called Monte Venere (Venus Mountain). This is a rounded hill with steep sides, whose summit is 317 meters above the lake level. The dense growth with which it is covered makes proper study of it difficult, but as far as I could judge it is a compact unstratified mass of eruptive rocks—a "dome" of leucite-trachyte. Part of the southeast flank is covered with pumiceous scoriæ, but elsewhere all such detrital material is lacking. Stoppani and Ricciardi mention a lava stream as flowing down its western side, which however I did not see, nor is it spoken of by Verri and Deecke.

From the ring wall of Vico the surface slopes gradually down on all sides at a low angle, except to the north where the Monti Cimini break the regularity. This surface is made up of yellow and gray tuffs containing leucitic, pumiceous, and some phonolitic blocks, as well as blocks of metamorphosed limestone, etc., such as are described by Deecke and Mercalli. Deep ravines—so characteristic of the surface topography of these regions—have been cut out by erosion, and diverge radially on all sides. Flank eruptions, which are so common at Bolsena, seem to be almost entirely wanting.

On the outskirts of the volcano the tuff and lava beds rest on late Eocene, and also in places on Pliocene deposits. Immediately to the south of the Vico crater lies the Bracciano region,

with its great crater lake, which will form the subject of the next paper.

It may also be noted that volcanic activity seems not yet entirely extinguished, since several hot springs occur in the neighborhood. The best known of these is that of Bulicame, which lies about 2^{km} to the west of Viterbo. This was probably known to the Romans, is mentioned by Dante, and is still flowing abundantly. The temperature of the water is 80°.[1] Verri also notes a few others near Ronciglione and Orte, and calls attention to the great deposits of travertine as evidence of the former abundance of mineral springs in the region.

We see from the above sketch that the structure of the region is somewhat different from that of the Bolsena region, since we find external to the great crater ring, and older than it, the Monti Cimini, and inside it the younger dome of Monte Venere.

A much more thorough study than has yet been attempted must be devoted to the region before all the problems it presents can be solved, but mention may here be made of the chief theories which have been proposed to account for some of its features. Since Verri's paper is the most detailed that we possess on the region it will not be out of place to quote briefly from his own résumé[2] of his views on the geological history and structure of the volcano.

According to him eruptions of fragmentary material broke out toward the close of the Pliocene period, and resulted in forming an island of trachytic tuff in the midst of the shallow sea. This was followed by eruptions of more solid material which formed Monte Cimino in the center of the island. After retreat of the sea consequent upon upheaval of the surface, which fractured the dome, trachytic lavas were poured out of the fissures thus made.

After this there was opened the Vico vent, both vents erupting simultaneously at first, though the eruptions of Monte Cimino soon ceased. With the opening of the Vico vent there

[1] DAUBENY, Volcanos. London, 1848, 160.

[2] VERRI, op. cit., 33.

appears a new mineral, leucite, which increases in abundance till toward the close it predominates largely over the other constituents. The eruptions of leucitic lavas were followed by those of lapilli, terminated by an explosion which threw out of the cone torrents of mud, burying the surrounding country for a distance of ten to fourteen kilometers.

The internal equilibrium of the cone was disturbed by the eruption of this vast amount of fragmentary material, and the greater part of the cone sank in, Monte Venere alone remaining above the waters of the lake—a fragment of the former summit which the action of the weather has reduced to a cone-shaped figure.

There are grave objections to be brought against certain points of this sketch, and Deecke devotes considerable space to arguments against two of them. He holds that Monte Cimino was not the result of a "domal" eruption of pasty trachytic magma followed by lava streams, as vom Rath and Verri believe, but that the mountain is part of what remains of the large crater ring of a true strato-volcano. The northwest wall of this has entirely disappeared and of the original cone only Monti Cimino, Valentano, La Pallanzana and one or two others are left. The crater was filled up, partly by its own eruptions and partly by the ejections from the neighboring Vico crater.

He agrees with Verri in thinking that the latest eruptions from the Cimino crater took place after those of Monte Vico had begun; but regards them as composed of "petrisco," which he considers with vom Rath to be a trachyte enclosing many leucites derived from the Vico lavas.

The arguments which he brings up against Verri's views that the crater lake of Vico is due to a sinking in of the top of the cone, and that Monte Venere is a half-sunken fragment, seem to me to be quite conclusive. They are so well given in his easily accessible paper that the reader is referred to it for a full presentation of them. He considers the crater a double one, due to powerful explosions, perhaps aided somewhat by sinking, and Monte Venere a true dome or *puy*—the last eruption of the

volcano. It may also be added that Stoppani combats Verri's views on these two points, as well as on the eruption of torrents of mud.

Though my own opportunities for observation were too limited to permit me to deal authoritatively with these problems, yet it may be of use to state briefly my own views. I am inclined to regard the Cimini eruptions as largely of a domal type, though lava streams and tuffs are more abundant than is usually the case with this type of volcano. Vom Rath's and Deecke's view as to the origin of the leucite phenocrysts in the "petrisco" I cannot agree with—a point which we shall have occasion to examine later on. I most decidedly concur with Deecke and Stoppani in considering the crater lake of Vico due chiefly to explosive eruptions, but think it probably a single crater, and that Monte Venere is a dome, representing the last eruption in the region. It is also well established that here, as at Bolsena, the leucitic lavas were later as a whole than the trachytic.

PETROGRAPHY.

We have to deal here, as in the Bolsena region, with two chief types of rocks, a trachytic and a leucitic. Petrographically the two regions are also alike in other more detailed features. The most important of these is the occurrence of a class of rocks intermediate between the trachytes and the andesites, which form a group of effusive rocks corresponding to some of Brögger's monzonites.

Vulsinite.—Of rocks corresponding to this type of intermediate effusive rocks characterized by the presence of both orthoclase and a basic plagioclase, there came to my notice only two occurrences, both being on the western border of the region. One is from Massa di San Sisto, about 7^{km} southwest of Viterbo on the road to Vetralla, where it forms a flow from the direction of Monte Fogliano cut through by the road. The upper part is visible here and there, though largely covered with travertine and leucitic tuffs. It is somewhat decomposed and fresh speci-

mens were hard to obtain. The other comes from near Vetralla 13^{km} southwest of Viterbo, from a quarry whose exact location I could not ascertain. It may be from the same flow as the one first mentioned since the two closely resemble each other. The second is a light gray, harsh, typically trachytic rock. The groundmass is fine-grained and contains small biotite and augite phenocrysts, with many glassy tabular feldspars. The sp. gr. of this rock is 2.611 at 11°. The first is similar in character, but its color is a light reddish brown due to atmospheric decomposition. The feldspars are larger than in the other, and much resemble the sanidines of the well-known Drachenfels trachyte.

Under the microscope the two present much the same appearance. The phenocrysts are of orthoclase with fewer of labradorite, which contain few inclusions, the labradorite being included in the orthoclase; many well-formed phenocrysts of pale green diopside, including patches of brown glass and some magnetite; and some of brown biotite (especially abundant in the second rock), which is much corroded and "altered," though generally a core of unaltered substance remains.

The groundmass is holocrystalline and typically trachytic. Many small colorless or very pale green diopside prisms and anhedra, with not abundant magnetite grains, lie in a paste of alkali feldspar and fewer plagioclase laths showing flow structure. Between these laths in the second rock there is some alkali feldspar as cement, which is almost entirely wanting in the first. Stout apatite prisms with gray dusty inclusions are very common, and there are also a few small brown biotite flakes.

An analysis of the Vetralla specimen is given in No. 1 of Table II. Comparison will show the great resemblance between it and that of the typical vulsinite from Bolsena.[1] Its mineralogical composition is also almost identical, though labradorite takes the place of anorthite and is somewhat less abundant apparently. It may be said that the rock was thought to be rather a plagioclase-bearing trachyte till the analysis showed its essential identity with vulsinite.

[1] This JOURNAL, IV, 552, 1896.

Very similar, if not identical rocks from the western part of the region are described by vom Rath and Mercalli, and Verri also speaks of them. The "biotite-hypersthene-trachyte" from I Capuccini at Monte La Pallanzana described by Rosenbusch[1] also belongs here. He speaks of labradorite as abundant. A section of this rock which I obtained from Sturtz belongs apparently to the "peperino" described later. Bucca does not mention these rocks but describes a "trachyte" from Casaccia, at the southern end of Lake Vico. In this, however, he mentions olivine as visible megascopically, and a plagioclase as abundant both as phenocrysts and in the groundmass so that it is probably to be referred to the following group of rocks. This is also probably the same rock as that from near Ronciglione which Mercalli briefly describes as an "andesitic olivine-trachyte."

Ciminite.—The main mass of the Monti Cimini is made up of a peculiar rock, which occurs in streams and perhaps also as domal masses. In several places this rests on Pliocene clays, which have been more or less metamorphosed at the contact.[2]

The proper position of this rock in our classification has been uncertain almost from the first. Vom Rath calls it a trachyte, while Deecke refers it to the augite-andesites, though each acknowledges that the name chosen does not quite agree with the characters of the rock. Vom Rath indeed says that were it not for its sanidine content it would fit better into the augite-andesites; while Deecke remarks that it approaches basalt on the one hand through its content of olivine, and trachyte on the other by its structure and large sanidines. Bucca describes the rock from Madonna della Quercia (which, as Deecke says, belongs here) as a trachyte; though he mentions, without commenting on the peculiarity, that the phenocrysts are chiefly of abundant olivine and augite, with few of feldspar. He describes the rock from Fontana di Fiesole as a leucitic trachyte, but speaks vaguely of "distinguishing two parts in the rock, one composed essentially of leucite, the other forming a rock similar

[1] ROSENBUSCH, Mikr. Phys., II, 771, 1896.

[2] VOM RATH, op. cit., 299.

to those described [trachytes]." We have already seen that his "trachyte" from Casaccia probably belongs here. Mercalli also calls the Cimino rock an olivine-trachyte.

I was unfortunately unable to obtain specimens from the main mass of Monte Cimino, but those which I collected from the flows back of Madonna della Quercia and at Fontana di Fiesole[1] are of essentially the same type of rock. A specimen from below San Rocco in the Vico crater probably belongs to this latter center of eruption.

These rocks are all very compact, one of my specimens from Fontana di Fiesole alone showing a few elongated vesicles. Their color is light gray, that from the Vico crater being slightly greenish. In the fine-grained groundmass are scattered abundant small phenocrysts of pale yellow olivine, with small black augites, and fewer small glassy sanidines, the rock from Madonna della Quercia showing the most of these last. The Fiesole rock has a sp. gr. of 2.70 at 10° C.

Under the microscope they present much the same features, the only marked differences being in the greater or less development of feldspar and pyroxene in the groundmass. Feldspar phenocrysts are very rare in the slides and are seen to be both of orthoclase and plagioclase. No sections of the latter were found by which its exact character could be definitely determined, though it seems to be a rather basic labradorite. The feldspar phenocrysts are much corroded.

There is a great abundance of large and small phenocrysts of olivine, but this does not occur as a true groundmass constituent. They show the normal forms, more or less corroded, and are colorless and perfectly fresh in the interior. All show, however, a narrow, bright reddish-brown border, so frequent on olivine, and apparently of the same substance as that which has received the name of iddingsite.[2] This covers original crystalline, corrosion, and fracture surfaces alike, though here and there a small

[1] DEECKE (op. cit., 240) states that this flow probably belongs to the Bolsena center. He does not give the reasons for this view, and my own observations leave no doubt in my mind that it belongs to Monte Cimino.

[2] A. C. LAWSON, Bull. Dept. Geol., Univ. Cal., I, 31, 1893.

fracture is seen which does not show it. I am inclined to agree with Deecke in the view that some action of the magma is responsible for the existence of this border, since, as in his specimens, the perfect freshness of all the other minerals seems to exclude any appreciable meteorologic decomposition. The olivine is quite free from inclusions, except a few magnetite grains.

Diopside phenocrysts are also abundant, in fact more so than those of olivine. Only the largest show in the section a faint green color, the great majority being quite colorless. They are all well formed and automorphic, showing the usual planes with a stout prismatic habit, but the largest have suffered somewhat in transit and are more or less fractured. The extinction angle on *b* (010) reaches 45°, that of the interior being slightly higher than that of the border. In a few cases olivine crystals were noticed protruding into, and hence older than, the diopside. In the rock from Madonna della Quercia a single large crystal of brown biotite was seen, associated with large crystals of feldspar. It was much corroded, being reduced to a carious condition.

All these lie in a groundmass which shows both andesitic and trachytic features. Except in the rock from Vico crater, where diopside is comparatively rare, there is a typically andesitic "felt" of small diopside needles with many magnetite grains, the interstices being filled with feldspar. This is in the form of laths and also of "cement." The laths are both of orthoclase and of plagioclase in much smaller amount. Carlsbad twins are sometimes seen in the former, but twinning lamellæ are rare in the latter, which is chiefly to be distinguished by its oblique extinction and higher refractive index. Both are surrounded occasionally by narrow mantles of orientated alkali feldspar. The cement is entirely of alkali feldspar. Little or no apatite was noticed. Glass is present in small amount in the rock from Madonna della Quercia, but is almost entirely lacking in the other specimens.

The above description will have made evident the difficulty of classifying these rocks. As has already been said, the scarcity

of orthoclase phenocrysts, the abundance of plagioclase and presence of olivine, with the andesitic structure of the groundmass, would incline one to call them andesites, while the abundance of orthoclase in the groundmass inclines one towards the trachytes. At the same time the olivine is much more abundant than is usually found in an andesite, and the striking feature of the comparative rarity of the feldspars among the phenocrysts gives them a decidedly lamprophyric aspect.

Similar difficulties are met with when we come to examine the analyses of these rocks given below:

TABLE I.

	1	2	3	4
SiO_2	55.44	58.67	56.32	56.76
Al_2O_3	18.60	15.07	18.17	16.79
Fe_2O_3	2.09	——	2.23	2.07
FeO	4.48	8.35	6.47	6.95
MgO	4.75	2.97	2.84	1.63
CaO	6.76	8.07	5.33	6.01
Na_2O	1.79	3.36	1.80	2.43
K_2O	6.63	3.50	4.18	4.67
H_2O	0.25	0.82	2.15	2.44
TiO_2	0.16	——	——	——
P_2O_5	Trace	——	0.34	0.47
Sum.	100.75	100.81	99.83	100.22
Sp. Gr.		2.765	2.520	2.470

1. Fontana Fiesole, Viterbo. H. S. Washington anal.
2. West slope of Monte Cimino. Vom Rath, *op. cit.* 304.
3. Mont' Alfina. Bolsena Region. Ricciardi anal. Klein, *op. cit.* 7.
4. Sassara. Bolsena Region. Ricciardi anal. Klein, *op. cit.* 7.

Here we see that while as regards the silica, alumina, iron and lime they approach the andesites rather than the trachytes, yet that the potash is largely in excess of the soda and that the rock is far richer in total alkalies than is the case with the true andesites. The magnesia also is abnormally high.

We see, then, that this rock can be properly classed neither with the andesites nor the trachytes, but that, like the vulsinite previously described,[1] it occupies a position intermediate between

[1] This JOURNAL, IV, 547, 1896.

the two. Its position is, however, not exactly intermediate, since the large amount of magnesia and the presence of olivine throw it somewhat out of line. For these effusive rocks, characterized mineralogically by the presence of orthoclase with basic plagioclase, augite or diopside, and olivine, and chemically by rather low silica (53–58 per cent.), high magnesia and potash, high alkalis, with more potash than soda, and andesitic amounts of alumina, iron, and lime, I would propose the name of *ciminite*,[1] from their earliest known and most characteristic locality. It may be mentioned here that these rocks, as well as the vulsinites, show many analogies with the absarokite-banakite series from the Yellowstone Park described by Iddings.[2] Their relations with these, as well as with the other trachy-andesitic and the leucitic rocks of Italy will be discussed in the final paper.

"*Peperino.*"—With the above may be described a rock concerning whose true character there has been much conflict of opinion. This is a soft, incoherent rock, easily cut with tools, which is much used for building purposes in the neighborhood. It goes locally by the name of "peperino," and was called by Brocchi "necrolite," on account of its use by the Etruscans for their sarcophagi and for the excavation of their tomb-chambers. It is quarried extensively at Bagnaia, to the east of Viterbo, where it rests on Pliocene beds and forms the oldest known product of the Ciminian eruptions.

This rock is called by vom Rath a trachyte, by Verri a trachytic tuff, by Mercalli a "quartz-bearing andesitic trachyte" or dacite, and by Deecke a mica-andesite. There is thus here, as in so many other instances, a great discrepancy among the various writers in regard to its character. The rock is too abundant, and too well known and much used in the region, and the descriptions tally too well to allow us to entertain the idea that the various observers are dealing with different materials. In this case I must decidedly agree with Verri in calling it a

[1] Pronounced chiminite.

[2] This JOURNAL, III, 935, 1895.

tuff, and consider it as derived from one of the peculiar trachy-andesites which are such a feature of this volcanic district.

I obtained my specimens fresh from the large quarries near Bagnaia, where it forms thick masses traversed by numerous fissures. Evidences of stratification were wanting. It is covered by looser beds of gray tuff containing, as pointed out by Verri and Deecke, many fragments of pumice and blocks of ciminite or a similar rock.

When first quarried it is very soft and friable, but hardens a great deal on exposure. It is rather coarse grained, made up of grains of feldspar, biotite, and augite, embedded in a finely granular paste. I could find none of the quartz mentioned by Mercalli. Its general color is a light yellowish gray, with spots and streaks of dark brown and gray, which give it somewhat the appearance of the well-known "piperno" of Pianura, near Naples.

Under the microscope it is seen to be composed of fragments of clear orthoclase, somewhat less abundant basic plagioclase (near labradorite) showing many twinning lamellæ, many brown and somewhat decomposed biotite crystals often frayed at the edges, and less numerous grayish green augites, all lying in a dusty, dirty, ill-defined groundmass. The fragmentary character of all the crystals is most marked, and there is lacking to all the constituents that definiteness of form and arrangement which characterizes true effusive rocks. The appearance is almost identical with that of many undoubted tuffs — so much so as to leave no doubt in my mind that the Bagnaia occurrences, at least, must be regarded as fragmental, and not effusive.

The only doubt cast upon this view is the presence in one slide of a large patch of obsidian. This shows similar, but much less broken, feldspar, biotite, and augite crystals, lying in a highly vitreous groundmass, which is made up of a clear, colorless isotropic base, flow structure being well brought out by abundant, damascene-like streaks of fine gray dust. These streaks curve about the large crystals, and also follow the line

of junction of the obsidian with the rest of the section. The contact line is rather vague, and close to the obsidian there are seen in the dusty groundmass some indications of a similar and parallel flow structure.

This patch might then be evidence in favor of the rock being a much decomposed and devitrified, highly vitreous, andesitic mica-trachyte, were it not for the wholly fragmentary condition of the crystals and the general similarity of the rock with other tuffs. The indications of flow structure seen in the dusty groundmass might be explained by the idea that they are due to the presence of part of the thin flake of obsidian extending beneath the tuff proper in the section. Such a flow structure is, however, clearly visible in such undoubted tuffs as those of Monte Epomeo on Ischia, and Monte Barbaro in the Phlegræan Fields and the obsidian-like patch may be due to secondary silicification. I may add that the view that the rock is a tuff accords better with the lack of contact metamorphism in the underlying Pliocene beds as commented on by Verri[1] and Deecke.[2]

Leucitic rocks.—These rocks, as we have seen, are confined apparently to the Vico center, though according to vom Rath and Deecke the latest ejections of the Cimino volcano were leucite-bearing.

There seems to be much less variety among the leucitic rocks of this region than was found among those of the Bolsena region. All the specimens which I collected may be referred to leucite-trachyte, and the same seems to be the case with those described by others, with a few exceptions to be noted presently.

Leucite-trachyte.[3]—This rock, which is known locally by the name of "*petrisco*," is very abundant in the region, forming flows and blocks in tuff around Monte Vico, as well as the domal Monte Venere. The flow occurrences are generally fresh, com-

[1] VERRI, op. cit., p. 26. [2] DEECKE, op. cit., p. 228.

[3] In Zirkel's sense, leucite phonolite of Rosenbusch. *Cf.* this JOURNAL, IV, 555, 1896.

pact, and extremely tough, while those forming ejected blocks in the tuff are so decomposed as to be very friable.

The flow specimens show a number of flat vesicles whose walls are smooth and occasionally coated with small crystals of nepheline, as was noticed by vom Rath. The groundmass is dark gray and very compact and aphanitic.

Through this are scattered leucite crystals in profusion, which make up in places over a third of the bulk of the rock and seldom fall below one-quarter, giving the rock a most characteristic appearance. The crystals are of good size, generally 0.5 to 1.0^{cm} in diameter, usually perfectly formed with sharp edges, but occasionally in fragments. While sometimes fresh and of the usual gray color and waxy luster (in one case yellowish through infiltration of ferruginous water), they are usually dull white, due to alteration. In the most altered specimens this kaolinization reduces them to a very friable and mealy condition. They include grains of augite and magnetite, which are irregularly arranged or clustered at the center. Apart from the leucites few phenocrysts are present, there being some sanidines and a few black augites.

In thin section the leucite-trachyte of Madonna di Lauro[1] near Vetralla, and that from a stream in the crater wall of Vico below San Rocco, which are typical of my Vico leucite rocks, present much the same characters. The large leucites are much cracked and exert little action on polarized light, the characteristic twinning being seen only in a few places. This is probably due to incipient or, as in the Vico rock, to evident alteration. There are not very abundant inclusions of augite, feldspar, magnetite, and glass. In the yellow leucites of one rock deposits of limonite are noted along all the crevices, while the leucite substance itself is quite colorless.

Feldspar phenocrysts are not uncommon, those of alkali feldspar being largely in the majority over those of plagioclase, which is a basic labradorite. Light brown glass inclusions are common, generally clustered toward the center. The pyroxene

[1] This is described by BUCCA, op. cit., 61.

phenocrysts are of a very pale green diopside and are highly automorphic. Some show evidences of fracture and corrosion, while a few have at the ends a late fringing growth of small diopside needles arranged parallel to the vertical axis. Except for a few large magnetite grains other phenocrysts are wanting.

The groundmass is decidedly andesitic in structure. Small stout needles of diopside, and of the brown pleochroic barkevikite-like hornblende seen in Bolsena leucite-tephrites,[1] many small alkali feldspars and a few plagioclase laths, and many well-shaped magnetites lie in a colorless glass base with absolutely no evidence of flow structure. Here and there are small round spots of a colorless substance whose inclusions and analogies with similar forms in others of these Italian rocks show them to be leucite, though their double refraction is scarcely visible. Apatite needles are also present in all the specimens. The colorless base is isotropic and seems to be entirely of glass. No nepheline could be detected with certainty. In one rock some alkali feldspar flakes are also present, and the glass in many places is of a light brown color.

Analyses of two of these rocks are given in Table II, Nos. 4 and 5. They resemble each other fairly well though 5 is lower in SiO_2 and Al_2O_3 and higher in iron oxides and lime. The analysis of the groundmass of a leucite-trachyte from the Vico Crater, by Ricciardi (No. 6), shows somewhat lower silica, extremely high alumina, considerably more lime, and less iron and alkalis. These are what we would expect to find, except the very high alumina, and perhaps the lower iron.

A few specimens of much decomposed petrisco from blocks in the latest tuff also deserve mention. They are so friable as to crumble readily between the fingers, rendering it difficult to obtain good specimens. The groundmass is black or brownish-black and very fine grained. This is thickly peppered with small and large leucites, with a few small sanidines, which stand out prominently against the dark background. The leucites in general are perfect and well formed, though some fragments

[1] Cf. this JOURNAL, IV, 562, 1896.

occur. They are all of a dull pure white and extremely friable —due to a process of kaolinization. A few small augite phenocrysts are also visible.

Under the microscope they resemble somewhat those just described, the differences being largely due to decomposition. The large leucites, many of which have fallen out, are of a pale yellow color and quite isotropic. The original leucite substance has given place to a peculiar alteration product which here and there is subfibrous in structure, but more often resembles a gum. It is filled with perlitic cracks which split it up into spheroidal masses.

The groundmass is very fine-grained and rather hyalopilitic in structure, formed of a felt of small diopside and alkali feldspar laths with magnetite grains, lying in a base either of brownish glass or glass with flakes of orthoclase. Scattered through it are small leucites, from 0.02 to 0.07^{mm}, which, though perfectly isotropic, leave absolutely no doubt as to their real nature, since they show the characteristic isolated inclusions, and often the still more characteristic skeleton forms previously described.

The leucites in these rocks, as well as in some of the flows, are supposed by vom Rath, Bucca, and Deecke to be inclosures derived from leucitic lavas of Monte Vico which were caught up during the eruption of Ciminian "trachytes." This view is based on the supposed facts that the leucite is always phenocrystic, is always or generally in fragments, is always kaolinized, and also on the chemical composition of the rock.

With this theory I cannot agree. In the first place my own observations lead me to agree with Verri (p. 29) in thinking that the greater part, if not all, of this petrisco-bearing tuff was derived from the Vico crater. Furthermore, the leucite, while chiefly present as phenocrysts, also occurs abundantly in the groundmass as we have seen. The fragmentary character of the large leucites did not appear to me to be nearly as universal as stated by the above writers; and even were it so it would not be surprising when the peculiar molecular condition of the mineral is

considered.[1] In all the occurrences which I saw and in all my hand-specimens the perfection of form of the tetragonal trisoctahedron is very striking, and furthermore the abundance of the leucites is too great to countenance the idea of their accidental presence. The state of alteration does not seem to me to have any bearing on the case, since this is dependent on surface conditions and would go on the same no matter what the origin of the crystals. The argument may rest on the ground that a trachytic magma would be at a higher temperature than a leucitic magma, but this idea is not expressed by either of the above writers. Vom Rath's analysis of petrisco is given in Table II (No. 6), and while it differs considerably from those of similar rocks from the Bolsena and other regions in containing less lime and magnesia and more silica and alkalis, yet it can be closely paralleled by analyses of similar rocks containing undoubtedly primary leucites to be described later.

The rock composing the dome of Monte Venere, which forms the last eruption of the region, is also a leucite-trachyte, but of a somewhat different type. The groundmass is very compact with only a few small vesicles, and the color is light gray. It is very tough under the hammer—a characteristic of most of the leucite rocks of all these regions. The leucite phenocrysts are neither as numerous nor do they stand out as prominently as in the preceding types, being small, quite fresh and glassy, and of a pale grayish white color. There is an abundance of very small phenocrysts of dark pyroxene and some small scales of biotite. The sp. gr. of this rock is 2.609 at 10° C.

Under the microscope leucite is seen to be a much more generally distributed constituent than in the preceding, or than the megascopical examination would lead us to suppose. It runs down from the larger phenocrysts to very small crystals of the groundmass, of which it forms a very large part. It seldom shows definite crystal boundaries; and inclusions, as well as double refraction, are rare.

Feldspar phenocrysts are common, and plagioclase is more

[1] Cf. ROSENBUSCH: Mikr. Phys., I, 311, 1892, and II, 826, 1896.

abundant than in the preceding rocks, which led Mercalli to call it a leucite-tephrite. They all carry very narrow irregular mantles of orientated alkali feldspar. The pyroxene is quite similar to those already described, but the green color is deeper and the augite molecule evidently surpasses that of the diopside. It frequently carries inclusions of apatite needles.

The most prominent difference in these Monte Venere rocks is the presence of quite numerous phenocrysts of brown biotite, which show strong pleochroism. They are quite fresh over the greater part of their area, but carry borders of large and loosely coherent augite and magnetite grains. A few are entirely altered and only represented by clusters of these grains showing roughly the original form. The groundmass is largely made up of small round leucite anhedra. Between these lie many laths and flakes of alkali feldspar, fewer augite microlites, and many magnetite grains, all of which are imbedded in a colorless glass base with no apparent flow structure. There is no evidence of the presence of nepheline. An analysis of this rock is given in Table II, No. 7.

The above descriptions embrace all the leucitic rocks collected by myself, but a few of a different character are described by other observers. Deecke mentions leucite-basanite as occurring on the south shore of Lake Vico, as well as among the lapilli of Monte Venere; and Mercalli notes a similar rock from San Martino, between Viterbo and Monte Fogliano. Bucca also describes an olivine-bearing leucite-tephrite from Capo d'Acqua, near Vetralla. Mercalli speaks of leucite-tephrites as occurring in several places, but his brief descriptions leave it uncertain whether leucite-trachytes are not intended. He also mentions a leucitic-phonolite as occurring in erratic blocks in the tuff which carries the phonolites described later. Deecke describes a number of leucite-phonolites (leucitophyrs) from Piazza, on the southeast shore of Lake Vico, from below San Rocco, and from Borghetto near Civita Castellana, east of the volcano. This last probably belongs to a flank eruption. They closely resemble the leucite-trachyte first described, except that they carry

nepheline in the groundmass. The apparently total absence of leucitites, which is commented on by Mercalli, is a most striking fact, and in great contrast to the adjacent centers of Bolsena and Bracciano.

Phonolites.—The presence of these rocks would seem to be an exception to the statement on a previous page that the Viterbo rocks can be divided into only two classes. They occupy, in fact, an exceptional position, occurring only as blocks in the last tuff ejected by Monte Vico and in a couple of dikes observed by Deecke. Their total amount is moreover very small, quite subordinate to those of the ciminites and leucite-trachytes. Of these rocks I collected three specimens. One is from a loose block in the yellow tuff west of Viterbo, another from a block in the tuff at the Posta on the north edge of the Vico crater. They are very compact and tough, with no great tendency to break into slabs under the hammer. In the aphanitic, greenish gray, slightly greasy groundmass are a few small glassy sanidine phenocrysts, stained light brown in places, still fewer small dark pyroxenes, and here and there a bright blue speck of haüyne. The sp. gr. is 2.509 at 10°.

Under the microscope it presents a normal phonolitic structure of Rosenbusch's nephelinitoid type. The large orthoclase phenocrysts are clear and free from inclusions, though a little brown limonitic material lies along the cracks. They are tabular parallel to the clinopinacoid, show commonly Carlsbad twinning, and often have corroded outlines. Mantles of orientated alkali feldspar are common. The rather rare augite phenocrysts are well formed and of an olive green color, and quite strongly pleochroic. Since the axis of greatest elasticity $\mathfrak{a}$ makes an angle of about 30° with the vertical axis they belong to the ægirine-augites.

Rather large haüynes are quite abundant and frequently show octahedral and cubic planes. They are generally colorless in the interior and bright blue toward the edge, though sometimes blue all over, or brown inside and blue out. They show the peculiar inclusions arranged in fine parallel straight lines, often

forming systems at right angles. These are best developed at the borders of the crystal. Haüyne is occasionally seen included in, and hence older than, large orthoclase phenocrysts.

The groundmass is holocrystalline and composed of small ægirine prisms and alkali feldspar laths scattered through a paste of nepheline, which occasionally shows characteristic crystal boundaries. The powdered rock gelatinizes abundantly with acids, the solution furnishing cubes of sodium chloride, and staining of the slides renders the identity of the nepheline certain. There are also present some small magnetite grains, quite abundant apatite needles, and a number of bright colorless highly refracting grains and crystals of titanite, which often show the characteristic pyramidal forms and rhombic sections. No leucite was seen.

An analysis of this rock by the writer is given in Table II, No. 9, the alkali percentages being the means of $Na_2O = 4.86$ and 4.90, and $K_2O = 9.21$ and 9.06, so that their relative amounts are beyond question. The analysis by vom Rath of his "phonolitic trachyte" is shown by No. 10. It would seem possible that there has been a transposition of the figures for the alkalis in vom Rath's paper.[1] This phonolite is then noteworthy for its very high potash content, which explains the large amount of orthoclase seen in thin sections. The amount of lime being very small and having been exhausted in the formation of diopside, and the potash having taken up most of the silica to form orthoclase the soda left from the ægirine went chiefly into nepheline rather than into albite.

Mercalli describes the above rocks under the name of "haüynitic sanidinite," but does not mention nepheline, though he says that they have the megascopic characters of phonolite. The description of the rock which vom Rath (p. 580) calls a phonolite-like trachyte from the Ciminian Mountains answers in every way to those just described, except that it is said by him to contain leucite and that it is quarried. The exact locality is not

[1] The discrepancy between the analysis and the description of the rock is commented on by ZIRKEL (Lehrbuch, II, 467).

given. He does not mention nepheline but speaks of a mineral in the groundmass which "may be sanidine," and states that the rock gelatinizes abundantly with HCl. The analysis (No. 9, Table II) is hardly that of a leucite phonolite, so that the rock may be classed as a phonolite with accessory leucite.

A phonolite of a somewhat different character is from a lava stream in the steep inner wall of Monte Vico, north of Monte Venere. This is a compact fine-grained gray rock, highly vesicular in structure, with a few small nepheline crystals visible on the walls of the vesicles. Glassy twinned tabular sanidines are abundant. Under the microscope it is seen to belong rather to the trachytoid type of Rosenbusch. The orthoclase phenocrysts are similar to those of the preceding specimens, but the rare pyroxene phenocrysts are rather augite proper than ægirine-augite. No haüyne is to be seen, but shreds of much altered brown biotite are found here and there. The groundmass is quite trachytic in character, the ægirine needles being less abundant and alkali feldspar laths much more so than in the other type, with marked flow structure. These, with considerable magnetite and some very small titanite grains, lie in a holocrystalline paste of what is apparently a mixture of orthoclase and nepheline. The former is in somewhat large flakes, and the latter distinguishable by its very weak double refraction and its behavior with acids.

Deecke describes some true phonolites which form two dikes in the eastern crater wall of Monte Vico. They correspond very closely to those described above. It is worthy of note that phonolite also occurs as a dike at Le Braidi on the eastern flank of Monte Vulture,[1] but has not been observed among the other products of this volcano.

Analyses.—In Table II are given the most reliable of the few analyses of the rocks of this region. No. 5 was made for me by Dr. A. Röhrig of Leipzig. No. 2 was made in the Mineralogical-Petrographical Laboratory of Yale University under the direction of Professor L. V. Pirsson, to whom I take the opportunity

[1] DEECKE, New Jahrb., B. Bd. VII, 602, 1891.

of returning my sincere thanks for his invaluable aid and advice. Nos. 7 and 9 were made in my own laboratory. The discussion of these analyses will be reserved for the final paper.

TABLE II.

	1	2	3	4	5	6	7	8	9	10
SiO_2	57.32	55.44	58.67	59.51	55.26	54.41	55.21	55.08	59.24	60.18
Al_2O_3	19.85	18.60	15.07	18.89	16.36	22.91	19.81	18.31	18.97	18.70
Fe_2O_3	2.21	2.09	....	....	5.26	1.45	2.69	1.67	3.30	....
FeO	2.35	4.48	8.35	5.26	2.90	4.67	2.86	7.06	1.20	3.44
MgO.....	1.60	4.75	2.97	1.50	1.14	1.54	1.68	2.18	0.12	0.32
CaO.....	3.82	6.76	8.07	1.90	3.90	6.73	4.61	5.79	2.06	2.80
Na_2O	3.22	1.79	3.36	4.99	4.08	[1] 1.64	3.13	[1] 1.34	4.87	9.67
K_2O	9.15	6.63	3.50	7.25	8.82	5.36	8.45	6.59	9.14	4.18
H_2O	0.57	0.25	0.82	0.56	1.20	1.53	0.99	2.19	0.86	0.33
TiO_2	....	0.16	....	....	0.36	....	Trace	....	0.48	....
P_2O_5	....	Trace	....	....	....	Trace	....	Trace	....	....
Cl.....	....		....	0.19	....	....	....	....	....	0.14
SO_3	....	....	....	....	....	....	....	....	0.10	0.19
	100.09	100.75	100.81	100.05	99.28	100.24	99.43	100.21	100.34	99.95
Sp. Gr.....	2.611	2.700	2.765	2.603	.....	.....	2.609	.....	2.509	2.522

1. Vulsinite, near Vetralla, H. S. Washington anal.
2. Ciminite, Fontana Fiesole, Viterbo, H. S. Washington anal.
3. Ciminite, West Slope of Monte Cimino, vom Rath, *op. cit.*, 304.
4. Leucite-Trachyte, "Petrisco," Viterbo, vom Rath, *op. cit.*, 298.
5. Leucite-Trachyte, Madonna di Lauro, Vetralla, A. Röhrig anal.
6. Leucite-Trachyte, *Groundmass*, Vico Crater, Ricciardi, *op. cit.*
7. Leucite-Trachyte, Monte Venere, H. S. Washington anal.
8. Leucite-Trachyte, *Groundmass*, Monte Venere, Ricciardi, *op. cit.*
9. Phonolite, block in Tuff, west of Viterbo, H. S. Washington anal.
10. Phonolite, Monti Cimini, vom Rath, *op. cit.*, 581.

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[1] Trace of Li_2O.